

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

*PREM*

*Personalised Residential Energy Model*

---

A thesis presented in fulfilment of the requirement for the degree  
Master of Applied Science  
in Natural Resource Engineering  
at Massey University, Palmerston North,  
New Zealand.

**Reto Keller**

**2004**

---

## Abstract

---

Climate change is a major world environmental problem accepted by these governments who have ratified the Kyoto Protocol which aims to reduce the amount of greenhouse gases (GHG) internationally 5% below the 1990 level during 2008 to 2012. The Protocol needed the ratification of Russia to get into force as the United States and Australia withdrew from the protocol. The New Zealand government ratified the protocol with the negotiated goal to reduce the GHGs back to the level of 1990. The main driver of this study is to help people reducing their personal GHG emissions in order to meet the government's objective of the Kyoto Protocol.

Many people know about climate change and understand they will need to change their lifestyle significantly to reduce their GHG emissions. The how and where to change is often unclear. People need to be incentivised in order to encourage emission reduction. Some GHG-calculators already exist, but mostly without practical personalised suggestions and financial effects. This study aimed to develop a model which targeted responses by individuals based on their lifestyle and interests.

The Personalised Residential Energy Model (PREM) which was developed in this study uses findings of energy related behaviours from existing psychological and technical research to develop an easy to handle and individualised computer model to assess a person's current energy demand. It includes household and travel demand and assesses the general ecological behaviour. Users will be provided with relevant information to assist them to seek practical and economic solutions in order to reduce their personal CO<sub>2</sub> (carbon dioxide) emissions which is the main GHG in the assessed sectors. Starting with the current situation as a baseline, it establishes which behaviours have the highest probability of being undertaken by the person to lower their energy demand. Information about the financial effect and the CO<sub>2</sub> emission reductions are provided for specific activities. Energy efficiency and conservation are the main focus of the model output. Further research could include the possible use of renewable energy.

Using PREM found changes in domestic dwellings and transportation vehicles to be an important factor in reducing anthropogenic CO<sub>2</sub> emissions. The model is made for New Zealand conditions but can be adapted to suit any other country.

---

## Acknowledgements

---

Central Power Electricity Trust is acknowledged for providing the funding to work one year on this thesis.

Assoc. Prof. Ralph Sims, who was my main supervisor, gave me the opportunity to start a thesis with him in the Centre for Energy Research and organised the funding, contacts and much more. He supported me with his broad experience and clear view which was invaluable. Thanks for your great support.

Dr. Patrick Dulin was my co-supervisor for the psychological field. It was extremely valuable to have his support since psychology was a new subject for me. Thanks for the patience and the time to lead me on the way to find the right approach to the environmental psychology.

Assoc. Prof. Florian Kaiser was very helpful by discussing the GEB-scale (General Ecological Behaviour), which he developed to measure people's environmental behaviour.

Many thanks to all who supported the thesis with the English correction: Andrew Smith, Simon Bernt, Paul Milsom and Danielle Poulos.

Finally I would like to acknowledge my parents who supported me in many ways during the entire time of my studies, also from Switzerland when I was in New Zealand. Thanks for trusting in the way I was going. It was a great experience!

Many thanks to all!

Table of contents

Abstract i

Acknowledgments ii

Table of contents iii

List of figures vii

List of tables ix

List of equations ix

1. Chapter Introduction 1

1.1. Objectives 2

1.2. Scope 4

1.3. Context 6

2. Chapter Literature Review 7

2.1. Introduction 7

2.2. Climate change 9

2.3. International conventions 15

2.4. New Zealand’s situation 20

2.5. Environmental costs 25

2.6. Household finances 28

2.7. Environmental psychology and behavioural changes 29

2.8. Renewable energies and improved technologies 30

2.9. Energy Efficiency and Energy Conservation 35

2.10. Energy Audit 37

2.11. Energy software 42

2.12. Summary 54

---

<b>3. Chapter Model Design</b>	<b>56</b>
3.1. Introduction	56
3.2. Methodology	57
3.3. General Ecological Behaviour	61
3.4. House construction	61
3.5. Transport	62
3.6. Appliances	64
3.7. Monthly bill	65
3.8. Improvements	66
3.9. Summary	67
<b>4. Chapter Psychometric Scales</b>	<b>68</b>
4.1. Introduction	68
4.2. Psychology and energy conservation	69
4.3. Theory of Planned Behaviour	74
4.4. General Ecological Behaviour	79
4.5. Rasch model	82
4.6. Summary	84
<b>5. Chapter Model Data Input</b>	<b>85</b>
5.1. Introduction	85
5.2. House construction	87
5.3. Electricity and fuel costs	89
5.4. Carbon - Tax	94
5.5. Electricity and fuel production	95
5.6. Transport	103
5.7. Appliances	110
5.8. Summary	122

<b>6. Chapter Model Verification</b>	<b>123</b>
6.1. Introduction	123
6.2. Case studies	124
6.3. Summary	132
<b>7. Chapter Further Research &amp; Conclusion</b>	<b>133</b>
7.1. Introduction	133
7.2. Further Research	135
7.3. Conclusion	139
<b>Reference list</b>	<b>142</b>
<b>Appendices</b>	<b>150</b>
A.1. Emission of Annex I parties 1990	150
A.2. Emission targets of the Annex B countries	151
A.3. Energy conversion factors	152
A.4. PREM – Manual	153
A.5. PREM Questionnaire	157
A.6. GEB scale	162
A.7. GEB - Questionnaire	165
A.8. Rasch formula	167
A.9. Maximum likelihood	168
A.10. House constructions	171
A.11. Conversion factor	172
A.12. Combustion emission factors	173
A.13. Highway distances	174
A.14. Fridges and freezer combinations, and freezer figures	175
A.15. Light bulbs	176
A.16. Television	176
A.17. Computers	177
A.18. Monitors	177



---

A.19. Case study inputs	178
A.20. Monthly bills	182
A.21. Monthly difference between Mr. Greeny and Mr. Careless	184
A.22. Improvement assumptions	185
A.23. Possible behaviour changes for Mr. Greeny and Mr. Careless	186
A.24. Hot water cylinder saving potential	188
A.25. House retrofit saving potential	189
A.26. Behaviours	190
A.27. Energywise Rally results	192

**CD - Appendix**

	File name
PREM-Model	A_28_PREM_Model.xls
Cars 2002	A_29_cars2002_AGO.xls
Cars 2003	A_30_cars2003_AGO.xls
Refrigerators	A_31_refrigerators2003.xls
Dryers	A_32_dryers2003.xls
Dishwashers	A_33_dishwashers2003.xls
Clothes washers	A_34_clotheswashers2003.xls



## List of figures

Figure 1: Personalised Residential Energy Model (PREM)	3
Figure 2: The parts of a person's life subdivided by basic activities.	4
Figure 3: The four stages of a device lifecycle. This study takes only the utilisation stage into account.	5
Figure 4: Setting the scene of this study for development of a Personalised Residential Energy Model (PREM)	7
Figure 5: The greenhouse effect.	9
Figure 6: Variation of the Earth's temperature for the past 140 years.	10
Figure 7: Variation of the Northern Hemisphere temperature for the past 1000 years.	11
Figure 8: Indicators of the human influence on the global atmospheric concentrations of three well mixed from 1000 AD and since.)	12
Figure 9: Simulated annual global mean surface temperatures as a result of natural radiative forcing, anthropogenic radiative forcing and both.	13
Figure 10: Timeline of the convention and the Protocol from 1979 until 1998.	17
Figure 11: Timeline of the convention and the Protocol from 1998 until 2002.	17
Figure 12: Kyoto Protocol target to reduce GHG emissions compared to business as usual.	18
Figure 13: New Zealand's GHG emissions during the period 1990 until 2000.	21
Figure 14: GHG emissions in New Zealand by sector.	21
Figure 15: Changes of GHG emissions in New Zealand from 1990 to 2000 by sector.	22
Figure 16: New Zealand's total consumer energy use by sector 1994-2000.	22
Figure 17: Energy sector GHG emissions 1999 measured in Global Warming Potential (GWP).	23
Figure 18: Gross CO <sub>2</sub> emissions of the New Zealand energy sector 1990-2001.	24
Figure 19: Insured losses in US\$ billions 1970 – 2002.	26
Figure 20: Natural catastrophes by category 2002. Source:	27
Figure 21: Real household consumption expenditure 1988-2001 in New Zealand.	28
Figure 22: Generation cost reductions from wind, photovoltaic (PV) and bioenergy projects from the mid 1980s till 2000.	31
Figure 23: Number of Earths required to support the human demand for natural capital.	44
Figure 24: Increase of the global hectares needed to supply human needs between 1961 and 1999.	45
Figure 25: Output example from the New Zealand's footprinter [m <sup>2</sup> /year].	46
Figure 26: Overview of a household used in the climate change calculator from the Australia's Environment Protection Authority.	47
Figure 27: Greenhouse report showing the CO <sub>2</sub> emissions (tonne per annum) in comparison with a typical person and a green household.	48
Figure 28: Energy costs (\$ per annum) split into different fuels in comparison with a typical and a green household.	49
Figure 29: Pollution report, possible to see five different pollutants. The figure shows SO <sub>x</sub>	49
Figure 30: Energy Advisor example of a final report of a house survey.	51
Figure 31: Energy Advisor suggestions to upgrade the house for better efficiency.	52

Figure 32: Personalised Residential Energy Model flow .....	60
Figure 33: Passenger transport energy use in New Zealand (excluding walking and cycling) .....	62
Figure 34: Auckland domestic sector mean annual electricity and gas-use breakdown. ....	64
Figure 35: Actors in energy conservation .....	71
Figure 36: The theory of reasoned action (TRA) .....	75
Figure 37: The theory of planned behaviour (TPB) .....	76
Figure 38: Person-Item logit scale for the basic Rasch model concept .....	82
Figure 39: Average domestic retail electricity price in New Zealand from 1974 to 2002. ....	89
Figure 40: Mains natural gas residential average prices in \$/GJ from 1974 to 2002. ....	90
Figure 41: LPG prices in cents/litre from 1991 to 2002. ....	91
Figure 42: Premium petrol (96 RON), regular petrol (91 RON) and diesel prices incl. GST in New Zealand between 1974 - 2002. ....	92
Figure 43: New Zealand's Electricity Generation in percentage by fuel 2001. ....	95
Figure 44: New Zealand's electricity generation CO <sub>2</sub> emissions in percentage by fuel 2001. ....	96
Figure 45: New Zealand's electricity generation CO <sub>2</sub> emissions in percentage by fuel for March year 2002 using LCA international emission factors .....	98
Figure 46: New Zealand's bus connections by InterCity Coachlines. ....	108
Figure 47: Incandescent vs CFL lightbulbs running costs .....	112
Figure 48: Fridges: Volume to energy consumption. ....	113
Figure 49: Rotary cloth dryer: Rated capacity to energy consumption per use. ....	116
Figure 50: Dishwasher energy consumption to the rated capacity. ....	117
Figure 51: Dishwasher energy consumption to the water consumption. ....	118
Figure 52: Cloth washing machine energy consumption to the rated capacity. ....	119
Figure 53: Clothes washing machine energy consumption to the total water consumption. ....	120
Figure 54: Monthly transport energy costs. ....	125
Figure 55: Monthly transport and household energy CO <sub>2</sub> emissions and carbon charge; a comparison between Mr. Greeny and Mr. Careless, assuming a carbon tax of NZ\$ 25/tonne CO <sub>2</sub> . ....	126
Figure 56: Monthly household energy costs for a range of appliances; .....	127
Figure 57: Monthly household energy CO <sub>2</sub> emissions and taxes; a comparison between Mr. Greeny and Mr. Careless, assuming a CO <sub>2</sub> tax of NZ\$ 25/tonne CO <sub>2</sub> . ....	128

List of tables

Table 1: Estimates of confidence in observed and projected changes in extreme weather and climate events. \_ 14

Table 2: Example of a wood price calculation based on the required heating energy for a house. \_\_\_\_\_ 93

Table 3: Electricity production CO<sub>2</sub> emission calculation for New Zealand generation in 2001. \_\_\_\_\_ 97

Table 4: Emission factor calculation for fuels in New Zealand. \_\_\_\_\_ 100

Table 5: Monthly total bill increase, separately assessed assuming an increase of each fuel price by 10% \_\_ 130

List of equations

Equation 1: Pay back time example for a fridge replacement \_\_\_\_\_ 66

Equation 2: Total savings of the investment \_\_\_\_\_ 66

Equation 3: Probability calculation by ability and difficulty \_\_\_\_\_ 167

Equation 4: Likelihood \_\_\_\_\_ 169

---

# 1. Chapter

# Introduction

---

Global warming has been a serious issue for more than a decade. Although not a general topic of conversation, many people and businesses have begun to realise the potential seriousness of the problem. This is particularly the case when they see the floods, storms and droughts in the news that could have been caused by global warming. Some governments are trying to respond through the Kyoto Protocol to reduce the emission of GHGs (greenhouse gases). This protocol would require signatories to reduce six greenhouse gases<sup>1</sup> during 2008-2012 at least 5% below the level of 1990. A high proportion of human produced greenhouse gases are emitted when energy and resources are used. The lower our energy and resource consumption, the fewer the produced GHG emissions.

Every society, government and industry is composed of individuals. To solve a problem such as global warming the majority of people need to recognise the issue. Factors affecting this recognition are primarily impacts on income and lifestyle and the closed eyes for the advantages. Resource efficiency is an attempt to reduce global warming. Seven good reasons for resource efficiency were outlined by Weizsäcker, Lovins, & Lovins (1997):

- Live better: Resource efficiency improves quality of live.
- Pollute and deplete less
- Make money. Resource efficiency is usually profitable: you don't have to pay now for the resources that aren't being turned into pollutants, and don't have to pay later to clean them up.
- Harness markets and enlist business
- Multiply use of scarce capital
- Increase security. Competition for resources causes or worsens international conflicts.
- Be equitable and have more employment

This research study shows how the actual personal energy consumption of a person can be identified, measured and a way found, adjusted to the individual user, to be resource efficient by reducing energy demand and CO<sub>2</sub> emissions.

---

<sup>1</sup> Carbon Dioxide (CO<sub>2</sub>), Methane (CH<sub>4</sub>), Nitrous Oxide (N<sub>2</sub>O), Perfluorocarbons (PFCs), Hydrofluorocarbons (HFCs) and Sulphur Hexafluoride (SF<sub>6</sub>)

## 1.1. Objectives

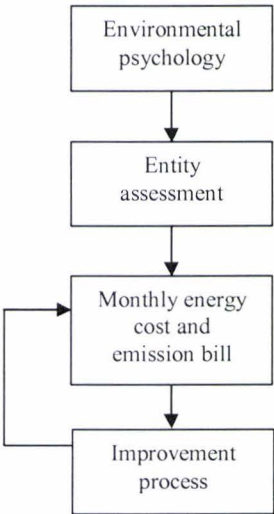
The general aim of this study was to determine the extent to which individual decisions and behaviour contribute to energy consumption, greenhouse gas emissions and cost savings. The thesis aimed to include environmental psychology into a technical based energy model to make it more individualised and subsequently, with the aid of psychological instruments, to determine how a specific person is most likely to change his or her behaviour to reduce GHG-emissions. The specific objectives of this study were to:

- develop a model implemented as a computer program to assess a person's household and transport energy usage, which will be shown in the form of a monthly bill;
- identify psychological methods to make behavioural changes more likely; and
- to add CO<sub>2</sub>-emissions and \$ values to certain behaviours which have environmental impacts.

Psychological research showed behaviour change is more likely if information is personalised, vivid and specific (Stern, 1992). "People typically over estimate energy use for lights and appliances that are visible and that must be actuated for each use, and they under estimate energy use for water heating or other less visible ends." This is where the connection between psychology and technical energy solutions become important. Using both psychological knowledge and the technical options, this model shows its users where, how and how much energy and hence CO<sub>2</sub> and money can be saved.

The entity assessment of the developed model in this study (Fig. 1) includes the energy use and CO<sub>2</sub> emissions from car models, public transport types and domestic dwellings, in order to identify the energy usage of each service with resulting costs and CO<sub>2</sub> emissions. The analysis of this information was used to calculate the monthly energy cost and emission bill adjusted to the specific person whereby emission will be shown as a dollar value too in order to make it more understandable.





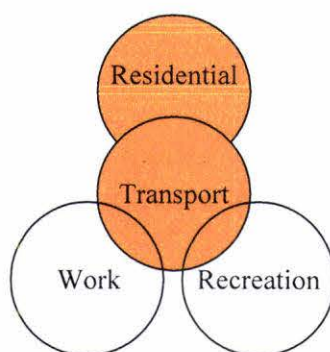
**Figure 1: Personalised Residential Energy Model (PREM)**

The model<sup>2</sup> allows the user to interact in an easy and slightly guided way as the improvement process (Fig. 1). All changes the user makes will immediately change the energy flows and the emissions. As a result the monthly bill will be adjusted. The model aims to find solutions to improve energy use and resource efficiency for the specific user based on the information provided.

<sup>2</sup> “The model” is always used to refer to the developed model in this study

## 1.2. Scope

Energy is used in every activity. This study will cover the energy use of a person's residential and transportation sector (Fig. 2). In this section a high proportion of a person's total consumption will be covered. The reason of this choice is, in ones own household and private transportation, the particular person is able to make decisions if desired and to change behaviour. It is also believed, if people see the pros of resource efficiency and its cost savings on their own, cost balance will then lead to more understanding and activities in industrial, agriculture and governmental based resource efficiency improvements.



**Figure 2: The parts of a person's life subdivided by basic activities. The living and transportation parts are covered in this study.**

People use energy with every activity in various forms. To develop a computer model in a Masters thesis with a timeline of a year the study needs to focus. The chosen scope was domestic transport and household energy usage including the utilisation stage of the dwellings.

The residential component contains household energy use with required heating, hot water and other associated dwellings. Topics not included in the study were consumerism (such as buying food and clothes), house construction (embodied and construction energy) and waste treatment from all these services. The transport sector included both individual and public transport for all main travel types (bike, car, plane, train and bus). The work sector was excluded due to the shared responsibility of the employer and employee. However the individual can also make a difference also at their work place. In our society recreation is



valued largely and the associated energy use is not expected to be small as a great number can afford hobbies such as riding a motor bike, motor boating, skiing, snowboarding or enjoying a day in an artificially heated pool. The recreation sector was only excluded due to time constraint.

Every technical device contains “embodied energy” as all of them have a life cycle which includes the development, realisation, utilisation and the final stage of disposal (Fig. 3). Each stage needs energy input and has GHG emissions as an output. To fully compare devices most accurately would be to take all four stages into account which requires a life cycle analysis (LCA). This study will concentrate mainly on the utilisation stage after the device is purchased and when it relies on direct energy inputs to provide the desired service.

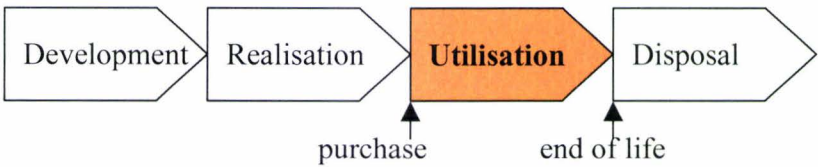


Figure 3: The four stages of a device lifecycle. This study takes only the utilisation stage into account.

### 1.3. Context

- Chapter 2 sets the scene with the literature review which explains the climate change science, national and international conventions and projects to tackle anthropogenic climate change, the costs caused by natural disasters and what other software in this field was produced.
- Chapter 3 explains the design of the model PREM.
- Chapter 4 shows general findings of environmental psychology and the approach used in this study.
- Chapter 5 provides information on the model's calculations and the data source used to develop the model.
- Chapter 6 describes how the developed model, was verified by using two different types of energy users. Mr. Greeny's and Mr. Carless energy usage were assessed and compared.
- Chapter 7 shows where further research could take place and concludes the thesis, by showing how the objectives were met.